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Introduction

Combined sewer overflows (CSOs) are increasingly being recognized as significant sources of water quality impairment in some urban areas of the United States. Several factors have contributed to CSOs not being adequately controlled despite the fact that they are covered under the Clean Water Act's National Pollutant Discharge Elimination System (NPDES) permitting requirements. They are a highly complex, site-specific technical problem that is expensive to control, and the U.S. Environmental Protection Agency (USEPA) has historically focused on regulation of single chemical pollutants (Water Policy Report 1994).

Combined sewer systems are state or municipally-owned wastewater collection systems that channel sanitary wastewaters and stormwater to a treatment facility. CSOs are discharges from the sewer system prior to the treatment facility of mixtures of untreated domestic sewage, industrial and commercial wastewaters, and stormwater runoff. CSOs usually result from a lack of sufficient storage capacity at times of high precipitation. They often carry high concentrations of bacteria and other microorganisms, suspended solids, toxic pollutants, floatable solid wastes, oil and grease, nutrients, and oxygen-demanding organic compounds (USEPA 1994a).

1.1 Document Purpose

One of the purposes of this paper is to investigate a potential tool for characterizing the biological effects of CSOs. It is hoped that such a tool would aid in achieving the characterization and monitoring portion of the Long-Term Control Plans. Part of the Long-Term Control Plan is to use cost-effective screening procedures for identifying relative degrees of impairment to the ecosystem; biological monitoring provides a mechanism for this. Additional objectives of the paper are to present two case studies in which biological assessments were used to evaluate CSO impacts, to investigate the effects of variation in sampling and analysis methodology on assessment results, and to examine potential application of bioassessment methods to the total maximum daily load (TMDL) process and other watershed management efforts. These efforts may include development of biological criteria, storm water and wet weather monitoring, and preparation of 305(b) reports, which are biennial reports prepared by each state to report the status of the state's waterbodies. The audience for this document is intended to be state bioassessment personnel, programmatic staff overseeing CSO management and control, and regional watershed protection coordinators.

1.2 Environmental Effects of CSOs

Many of the limited existing data on CSOs are measurements of effluent levels of physicochemical water quality parameters (i.e., they measure stressors in the CSO directly). Stressors contained in CSOs may be physical (e.g., elevated temperatures, high velocity, heavy solids load), chemical (e.g., organic loading, biochemical oxygen demand, toxic pollutants), or biological (fecal coliforms) in nature. The high energy and intermittent flows characteristic of CSO discharges result in several physical effects in the receiving waterbody, among them scouring of the substrate, bank destabilization and erosion, and changes in the morphometry (shape) of the waterbody (e.g., increased channelization). The problems are probably most evident in lotic (flowing) waters, and particularly where there is a steep topographical gradient. The magnitude of the physical changes in the waterbody is dependent on the topography and geology of the area (e.g., how easily the substrate is eroded), the volume and flow of the discharge, the intensity of the storm event(s), and the amount of increase over "normal" flow. It should be noted that these physical effects are a function of the wet-weather flows and discharges, not CSOs in particular; storm water discharges can exert similar effects.

Numerous biological effects can occur in the aquatic ecosystem from the high flow. There might be an immediate, direct loss of organisms and their habitats. For example, in streams and rivers, plants and animals might not be able to withstand the greatly increased flows and might be swept downstream (Seager and Abrahams 1990), where they might or might not find suitable habitat. The high and intermittent flows could preclude the establishment or maintenance of vegetated areas once they have been uprooted or undermined by the flow, and curtail recolonization by benthic organisms after downstream drift. Thus, the loss of habitat and organisms might be perpetuated.

CSO discharges are usually warmer than the receiving waterbody, especially in summer. Moreover, urban streams often lack shade, which raises ambient summertime temperatures. The heavy sediment load in CSOs can influence heat radiation in the water column (USEPA 1992), possibly by increasing heat retention by the particles in the water column, thus maintaining the elevated temperatures. Warm water cannot hold oxygen in solution as well as cold; therefore, an indirect result of elevated temperature is lower dissolved oxygen in the water column.

While suspended in the water column, particulate matter results in increased turbidity and reduced light penetration. Ambient light levels can be further lowered by color generated by materials in the discharges (or produced later by subsequent algal blooms). Much of the material in CSOs and storm water/runoff is relatively large (Field and Turkeltaub 1981). In such a case the majority of the material would settle out relatively quickly and light levels could return to normal. If there is a significant percentage of fine-grained silt and clays, however, the settling rates are much slower and the elevated turbidity levels can be more or less permanent. The high flows characteristic of CSOs can often cause a resuspension of potentially contaminated sediments (including microbes and pathogens, toxic substances, and metals) deposited from earlier storms.

CSOs have high levels of organic matter, which contribute to biochemical and chemical oxygen demand (BOD, COD) and thus to dissolved oxygen (DO) depletion in the water and sediments. There appear to be immediate and delayed stages in the high oxygen demand dynamics. There is an immediate (i.e., during the storm event) peak of COD (Ellis et al. 1992), due to the physical forces that scour, flush, and resuspend the sediment and associated material and due to the relatively rapid degradation of the dissolved organic compound portion of BOD. The delayed effects are due to the degradation of the BOD associated with the particulate matter (Lijklema et al. 1990; Hvitved-Jacobsen 1982), which is more refractory.

The toxic contents of CSOs are not well characterized because they are site-specific, storm-specific, and dependent on the relative proportions of the industrial waste, domestic waste, and storm water components along with the individual characteristics of each component. However, numerous constituents that are highly toxic to aquatic life have been documented in CSOs . These include heavy metals (copper, lead, zinc, etc.), PAHs, and pesticides. Non-priority pollutant toxic substances are also found. Ammonia might be present in the discharge itself, shown by peaks in instream NH_3-N concentrations during a storm event (Ellis et al. 1992). Ammonia might also be generated within the sediment and released to the water column. Also present are oil, grease, and gasoline, which have toxic effects of their own and might be further contaminated with various priority pollutants. There might be whole-effluent toxicity due to mixtures or unknown constituents as well.

1.3 Biological Assessments

Biological assessments provide integrated evaluations of water resource quality. They also can allow inferences to be drawn from a broad array of stressors based on both biological and physical habitat conditions. Impairments can be identified from a variety of sources including water column contamination, sediment contamination, nonchemical impacts, and alteration of physical habitat (Karr 1991). The instream communities act as continuous monitors of water quality, assimilating impacts from periodic spills, nonpoint source pollution, cumulative pollutants, and other sources that might be missed during sporadic chemical sampling (Ohio EPA 1987a; USEPA 1990a). Responses to natural habitat variability and impacts from intermittent physical habitat change precipitated by phenomena such as increased stormflows (e.g., sedimentation, scour, and modified flow characteristics) will also be reflected by the biological community (Heins 1991; Burton and Harvey 1990; Holomuzki 1991; Chambers et al. 1991; Jowett and Duncan 1990; Burns 1991; Plafkin et al. 1989; Barbour and Stribling 1991; Karr et al. 1986; Ohio EPA 1987b). Because of the unpredictable and fluctuating nature of storm events in urbanized watersheds (Schueler 1987), characterization of the biological community might provide a good measure of the cumulative instream effects caused by CSOs and stormwater discharge.

Rapid bioassessment protocols (RBPs) have been developed for determining the status of macroinvertebrate and fish community structure and function in streams and wadable rivers (Plafkin et al. 1989). These methods provide a relatively quick and cost-effective means of compiling and analyzing information on the impairment of aquatic communities from point or nonpoint source pollution. RBPs currently serve as the foundation of the bioassessment approach being adapted by many water quality agencies across the country. Forty-five states have implemented or are developing biological monitoring programs modeled after the RBPs or some other multiple-parameter (multimetric) approach for characterizing benthic macroinvertebrate communities in the context of habitat quality (Southerland and Stribling 1995). The RBP concept is well-founded in ecological principles and uses an information-gathering structure that categorizes and assimilates information into community parameters or metrics through the use of habitat and biological community assessments.

The biological community analysis consists of standardized field collection of benthic macroinvertebrates, and subsequent calculation of a series of "metrics," each measuring a different aspect of community structure and composition. The assessment integrates the metrics and compares them to reference values, allowing judgments to be made on what could be expected at the test site if habitat and pollutant impairments were corrected, as well as the current judgment of overall biotic impairment. The investigator can also evaluate the generic causes of impairments by examining the individual metrics (Yoder 1991; Yoder and Rankin 1995; Shackleford 1988). Different types of organisms have distinct reactions to various types of stresses. For example, metrics which focus on invertebrates that rely on particulate organic matter, such as leaf litter for food, could be used as a screening tool for assessing the impact of bound contaminants or degradation of the riparian vegetation.

Useful metrics for application of RBPs can vary by waterbody type and geographic region (Plafkin et al. 1989; Barbour et al. 1992). Ideally, they are selected based on criteria that would document relevance, sensitivity, responsiveness, and practicality (Barbour et al. 1995). Following pilot studies and evaluation of data and metrics, some might be discarded based on failure to meet pertinent criteria. Although the metrics used for the Ohio and New York studies were taken directly from Plafkin et al. (1989) and Barbour et al. (1992), their use does not necessarily imply that they are the most appropriate choices relative to desirable criteria for metrics, such as responsiveness to environmental degradation. Additional metrics might be more appropriate for assessing CSOs, but developing and testing metrics was beyond the scope of this project.

1.4 Reference Conditions

RBPs are based on the concept of comparison between a study area and a reference condition or site. A reference condition is the set of conditions of minimally impaired waterbodies characteristic of a waterbody type for a given region or subregion (Gibson 1994). The *reference condition* is made up of data from reference sites in a geographic area (or "ecoregion") for waterbodies of the same class and serves as the benchmark for determining the biological potential of test sites in that geographic region and of the same class; it gives more accurate description of expected conditions and the natural variability than do site-specific reference sites. Regional calibration of metrics allows for fine tuning of biological information so that the most appropriate metrics are used for each specified ecological stratum (e.g., type of waterbody) and the regional boundaries for metric variability are recognized.

A *reference site* is a specific locality on a waterbody that represents the expected biological integrity for other sites on the same (site-specific reference site) or nearby waterbodies (regional reference site). Site-specific reference sites have the potential to be affected by stressors affecting the watershed. For that reason, we currently recommend that several reference sites be used for comparisons if reference conditions have not yet been developed for the region and site class. As more site-specific reference sites are sampled and metrics tested and calibrated, they will serve as the foundation for building a reference condition database for waterbodies in the same class and region. Further discussion on the topic of ecological reference conditions and site-specific reference data can be found in Hughes (1995).

The current study used one site-specific (upstream) reference site and one regional reference site as the benchmark to determine the biological impairment of the test sites. In some cases the regional reference site was determined to be unsuitable for use as a reference due to impaired biological condition; in these cases the site-specific reference site was used for comparison. For the current Ohio study, single regional reference sites were used in addition to the upstream reference sites; however, the historical assessments for Ohio are based on the regional reference condition. Two of the three rivers in the current Ohio study (Scioto and Sandusky) are in the same ecoregion (Eastern Cornbelt Plains) and thus might not have required separate scoring criteria if regional calibration had been performed. This could be the source of some differences in the biological assessment for some sites between historic and current assessments. For the most part, regional reference conditions provide more general criteria for acceptable biological integrity.